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THESIS

HOVER PERFORMANCE OF A
REMOTELY PILOTED HELICOPTER

by

Randolph Pierre Cotten

December 1986

Thesis Advisor: Donald M. Layton

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Hover performance of a Remotely Piloted Helicopter

by

Randolph P. Cotten
Major, United States Marine Corps
B.S., University of Wyoming, 1970

Submitted in partial fulfillment of the
requirements for the degree of

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December 1986

ABSTRACT

This paper discusses the hover performance of a remotely piloted helicopter (RPH) and the suitability of the use of this RPH in the academic environment of the Naval Postgraduate School Aeronautical Engineering Department. The methods used are those used in the Helicopter Performance Test Manual of the U.S. Navy Test Pilot School. When testing remotely piloted aircraft for use with the military, there is a necessity to test a product to specifications. These specifications may be similar to those of a full sized aircraft. The test methods used are adequate for the testing of RPH's for specification but the use of this equipment in an academic environment is not safe enough without major modification. The RPH has enough excess lift to carry a small test instrumentation package in forward flight. If the RPH is used only in a laboratory environment for the demonstration of hover performance; the gas engine can be replaced with an electric motor and a plexiglas shield can be used between the students and the RPH to satisfy necessary safety precautions.

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I. INTRODUCTION

A. GENERAL HISTORY

In the early nineteenth century, an improved version of a French helicopter was successfully flown [Ref. 1]. Scaled down helicopters were recognized by the early pioneers in helicopters. Layley, Launcy, and Bienvenu were early designers of helicopters and their potential; including scaled down models. Igor Sikorsky is credited with the first practical full sized helicopter in 1939, the VS-300, which had a functional solution to the stability and control problems of the time and a useful payload. From these beginnings, the modern day helicopter has evolved into very sophisticated and versatile aircraft.

B. RECENT PROGRESS

As technology has advanced, modern warfare has made detection and destruction of aircraft easier. Systems are being developed to protect manned aircraft or decoy weapon systems away from manned aircraft. The latter is where remotely piloted vehicles (RPV) are becoming more and more important. Rather than fill a helicopter with personnel for an aerial reconnaissance, a remotely piloted helicopter (RPH) with attached sensors may do the same job without hazarding personnel or a much more expensive aircraft. Model

fixed wing aircraft have been remotely piloted for many years. Only recently, as compared to model fixed winged aircraft, have model helicopters been flown. The first successful radio controlled model helicopter flight was completed on 12 April 1970 by Dieter Schluter. The flight lasted 5 minutes [Ref. 2]. Both RPV's and RPH's have advantages and disadvantages. RPV's can fly at a relatively high altitude and can be very quiet but require a trapping mechanism to capture the vehicle upon return. An RPH can be landed with no other equipment and in comparatively small unprepared areas but have a much higher noise level.

C. HISTORY OF THIS PROJECT

This project was originally started by Captain C. J. Hintze, USA, when he constructed this Heli-Star remotely piloted helicopter (RPH) from a kit for the Aeronautical Engineering Department of the Naval Postgraduate School [Ref. 3]. This helicopter was intended to be used in some manner in the study of the aerodynamics of helicopters in a laboratory setting. Exactly how it was to be used had not been determined. Capt. Hintze suggested the RPH could be used to study the differences between full sized and scaled down helicopters. Performance parameters were considered to be the first measurements to be studied. One of the most significant performance parameters of a helicopter is the vertical lifting capability. As such, Lieutenant T. J. Urda

undertook a project to develop a device to measure the hover performance of the RPH [Ref. 1].

D. OBJECTIVE AND SCOPE

This project was undertaken to continue the process of developing a means of utilizing the RPH as a laboratory tool at the Naval Postgraduate School. The objective of this project was:

1. Utilize the test stand as designed by Lieutenant Urda with no changes to determine if the minimum sophistication employed is adequate to take acceptable data.

2. Determine if the test techniques used in [Ref. 4] on full size helicopters can be utilized on RPH's.

3. Grade the amount of operator expertise to take the data and operate the equipment. Depending on this and the data collected, evaluate the RPH and test stand as an academic tool.

4. If the equipment can be used as an academic tool, deduce how and in what capacity it may be used.

II. APPROACH

A. CONSIDERATIONS

In order to obtain hover performance data, a decision was required as to what parameters were to be measured and by what method. In order to take data for hover performance, there were several methods available that are similar to those used in full sized aircraft testing. In addition, operator familiarity and helicopter preparation/maintenance were required prior to the taking of data. The following are a discussion of some of the methods, the reasoning for accepting or rejecting each method, and the operator and helicopter preparation.

B. THRUST MEASUREMENT

1. Free Flight

Free flight as used in full size helicopter testing was not considered seriously due to the lack of instrumentation that could be put the RPH. Highly complicated equipment would be required to telemeter the data to the ground. Above all, high operator proficiency would be required to free fly the RPH well enough to obtain usable data.

2. Tethered Flight

The original idea was to used the method of tethered hover. The tethered hover method is the preferred method for full size helicopters because this method is exact and produces excellent results [Ref. 5]. The aircraft is secured to the surface by a known length cable. The weight of the cable is added to the weight of the aircraft for calculations. There is a load cell attached between the cable and the aircraft in order to measure the amount of lift the rotor system is producing. The pilot is required to maintain a constant heading and keep the aircraft directly above the attachment point on the surface with no aircraft movement. If this procedure were applied to the RPH, pilot proficiency would have to be very high in order to keep all the possible variables constant. This procedure was not selected because of the high pilot proficiency required and the amount of flight time required to obtain that proficiency [Ref. 1]. Additionally, there is always the ever present possibility of crashing the RPH while conducting these tests.

3. Sliding Shaft Design

A variation of the tethered hover method is the sliding shaft. This design would allow the RPH to be attached to the test apparatus and eliminate the need for high pilot proficiency and reduce the possibility of crashing. Figure B.1 is a drawing of the sliding shaft design. The shaft is 6 feet long. At the base is attached a load cell

which is in turn attached to a wooden support stanchion (2"x4"). The attachment points can be adjusted in 1 inch increments up and down in order to adjust the hover height. At the top of the shaft, the RPH is rigidly attached. This entire apparatus is attached such that the RPH is above the floor and the shaft goes through a hole in the floor. By raising or lowering the shaft on the support stanchion, the RPH can be raised or lowered in or out of ground effect. The pull of the RPH on the load cell is used to determine the lift produced by the RPH. The load cell selected was the Interface, Inc., Super-Mini load cell, model number SM-25. The load cell electrical schematic is presented in Figure B.2. The load cell was calibrated with an excitation voltage of 9.004 volts and the raw data is presented in Table A.I [Ref. 1].

C. POWER MEASUREMENTS

The engine was manufactured in Austria and no immediate information was available [Ref. 4]. In order to obtain any testable relation between engine rpm and power would require independent testing. Testing locally would require the purchase of a dynamometer at a cost of $1000-$2000 and disassembly and reassembly of the RPH. The other alternative would be to instrument the engine power shaft on the helicopter. This is quite difficult due to the small size and location of the engine shaft. The manufacturer was

contacted and information relating engine rpm and power was obtained. The data received was in watts and metric horsepower vs. engine rpm. [Ref. 4]

The following was used and the translation between metric and english units:

1 metric hp = 735.5 watts = 0.986 english hp

The relation between engine rpm and engine power is presented in Tables A.II and A.III. This last approach was chosen because of ease of incorporation and had sufficient accuracy for the intended use of the data. [Ref. 1]

In order to correlate the power to the rpm, the rpm had to be measured. A magnetic pickup was used to measure engine and rotor rpm. Figure B.3 shows the magnetic pick-up in relation to the first engine driven gear. The reason a single pick-up was used was to simplify the instrumentation [Ref. 4]. The wire is routed beneath the RPH and is weighted down on the floor prior to being attached to a counter. The teeth were counted on the gear train of the RPH and the following ratios were established [Ref. 4]:

Engine gear teeth 10

Main rotor gear teeth 80

Main rotor speed = Engine speed/8

Tail rotor teeth 70

Bevel tail rotor teeth 15

Tail rotor turns to main rotor turns 65/18

Tail rotor speed = 3.617 * Main rotor speed

Tail rotor speed = Engine speed/2.212

D. HELICOPTER PREPARATION

The RPH was in need of some repair prior to the initial startup. During the previous testing and validation of the test stand, the RPH had experienced vibration problems [Ref. 1]. New blades had been purchased for the RPH but had not been balanced. A simple method as outlined in [Ref. 2] was used. The two blades were bolted together at the blade grip attachment points. The bolt was long enough to protrude approximately 1/2 inch on each side. The bolts were then put on two razor blades mounted in two wooden blocks, Figure B.4. Blade tape, provided with the new blades, was then used to balance the blades such that when disturbed, the blades stopped with the tips equidistant from the table top.

Once the blades were balanced, the blades needed to be adjusted in pitch to rotate in the same plane. Instead of attempting to track the blades and set the correct pitch for flying, the RPH was taken to a local RPH model flying club. One of the more experienced operators set the pitch by means of a pitch setting device (Figure B.5), tracked the blades by trial and error, and tuned the carburetor. He then flew the RPH to ensure that this set-up was correct.

E. OPERATOR PREPARATION

Operator familiarity with the equipment was not very extensive at the beginning and remained fairly low throughout testing. The first time the RPH was started, the remote control was inadvertently turned off, and the RPH went to full throttle. With the remote control off, directional control was lost. The RPH began spinning and the tail rotor struck the starting battery. The remote control was finally turned on and the RPH was shut down. One tail rotor had broken off, the blade grip had a broken pitch change link, and the tail rotor control rod was twisted around the tail rotor shaft. New blade grips and a tail rotor control rod were ordered and installed. Several more trial runs were completed with the learning curve increasing with each successful start. Finally, the RPH was in adequate running condition and operator familiarity was high enough not to damage the RPH when taking data.

III. TESTING AND RESULTS

A. DESCRIPTION OF EQUIPMENT

1. The Helicopter

The RPH is a Schluter model Heli-Star. The RPH without the nose cover is shown in Figure B.6. The main rotor is a symmetrical airfoil 52.31 inches in diameter. The cord is 2.57 inches and is 0.39 inches thick. The main rotor is 14.3 inches above the bottom of the skids. The tail rotor is another symmetrical airfoil 10.5 inches in diameter. The cord is 1 inch and is 0.35 inches thick. The the tail rotor hub is 31.25 inches aft of the main rotor and the nose, without the cover, is 18 inches ahead of the main rotor. The overall length from tip of main rotor to tail rotor is approximately 62.7 inches long. The width at the skids is 12.6 inches.

The RPH is powered by a HP-61 Gold Cup series 2-cycle engine manufactured by Hirtenberger of Austria. The bore is 24.5 mm, a stroke of 21 mm, giving a displacement of 9.89 ccm. The fuel consists of a mixture of normal glofuel with 5-15% nitro-methane. The engine rpm range is from 2400 to 20000 rpm.

The RPH is controlled with four radio controlled servos model FP-S28 made by Futaba Corporation. One servo each controls cyclic pitch and roll and one for the tail

rotor. The remaining servo controlled both the collective pitch and the engine rpm. Using only one servo did not allow the independent control of these two parameters. The servos are remotely controled by a four channel digital proportional radio controller model FP-4L also made by Futaba Corporation, Figure B.7. Both the servos and controller are powered by rechargeable nickel-cadmium batteries.

The RPH was operated without nose cover because of the difficulties in controlling engine speed. If the engine could not be shut down, all controls could be reached with the RPH running.

2. The Test Equipment

The test equipment is shown in Figure B.8. The volt meter was a Fluke Digital Multimeter, model 8600A serial #0855115. The voltage supply for the loadcell was a SRC Division/Moxon Incorporated model 3564 serial #14061. The digital counter was a Monsanto Counter Timer model 101A serial #675A460. The temperature and barometric reading were taken from a Noymer temperature and barometric indicators (not shown in Figure B.8).

The RPH is mounted to the sliding shaft via a plate mounted on the skids. The mounting devices are plastic ties, Figure B.9. The plate is visually aligned with the main rotor shaft such that the rotor shaft is in-line with the sliding shaft.

B. TEST AREA

The test area is shown in Figures B.10, B.11, and B.12. There are numerous walls, tables, and other obstructions immediately around the RPH when mounted on the sliding shaft.

C. DATA

Hover data was taken at three skid heights, 2, 10, and 35 inches at 19°C and 30.11 inches Hg pressure. The data taken is presented in Table A.IV.

Only one set of data was able to be taken. When the RPH was started for subsequent data, the engine could not be controlled properly. The carburetor had become loose and when tightened, could not be properly adjusted to control the rpm.

The suggested procedures followed to adjust the carburetor came from [Ref. 2]. Once the RPH was started, the rpm was allowed to increase so that the high rpm fuel to air mixture could be set first. This required the operator to reach underneath the rotating main rotor to make the proper adjustments. The main rotor is only 14.3 inches above the bottom of the skids. This did not allow much room for safety between the operator and the turning rotor.

During previous familiarity operations, the maximum engine rpm attained was approximately 13000 rpm. When taking the hover data, the maximum engine rpm was limited to approximately 12000 engine rpm. This limit was based on the

sound of the engine as compared to the maximum rpm of RPH's operated by local hobbyists. This rpm is considered to be maximum continuous rpm by these hobbyists.

When the RPH was in operation, the ventilation in the testing area was not adequate to exhaust the fumes. In approximately 20 minutes after starting, the fumes were noticable in smell and in minor irritation to the eyes and nose.

At all heights, but notably at 35 inches, the main rotor tip-path-plane oscillated in a counter-clockwise direction at a slow frequency. This frequency was dependent on the main rotor rpm but was observed to be approximately 2 Hz. These oscillations could not be stopped with any of the controls.

D. RESULTS

The data was reduced using the data reduction methods outlined in the hover performance section of [Ref. 5] using a standard rotor rpm as 1350. This standard rotor rpm was chosen as the approximate median of the data taken. The fuel used at each hover height could not be measured directly. The fuel burned between the different hover heights was about 0.1 lbf, therefore the starting weight was assumed constant at each hover height. A short basic program incorporating these methods was written to reduce the data and is included in Appendix D. The reduced data is presented in

Table V. Figures B.13 and B.14 show the data in a manner consistent with [Ref. 5]. The lines in the figure represent the data for the three different hover heights.

E. DISCUSSION

The data taken from the loadcell had a low confidence factor and are suspect because of the large fluctuations on the digital voltmeter. The fluctuations were up to $\pm$0.5 mv on the voltmeter.

The voltmeter data was mentally averaged when the data was taken. Considering the averaging, the data still showed that more power was required to lift the same weight as the hover height was increased. This is an expected result of helicopter hover performance. The slope of the line should decrease from the lowest hover height to the highest hover height. The data did show this trend but with a fluctuation of $\pm$0.5 mv on the loadcell, a variation of up to $\pm$3.92 in weight referred$^{3/2}$ could occur. This variation would allow the slope of each line to change significantly.

There are several reasons for these fluctuations: (1) because of obstructions located close to the RPH, the air flow from the rotor system could not circulate properly, (2) the flooring was 1/2" plywood laying on open metal grating, Figure B.15, which had minimum rigidity and moved when walked upon, and (3) the supoort stanchion on which the loadcell was mounted was rigidly attached to the underside

of the test flooring, which would transmit any vibrations of the flooring to the loadcell.

The data was reducted by the methods outlined in [Ref. 5]. When the weight referred is taken to the 3/2 power and plotted versus the referred engine shaft horsepower, the data points should all lie on a straight line with the intercept of all the lines on the abscissa being the profile power of the rotor system. The data was entered into a linear regression program without regard to the profile power and the abscissa intercept (profile power) was -9.248 to -0.1956 ESHP referred. This made the raw data more suspect because the profile power cannot be negative. The profile power for the main rotor and the tail rotor were calculated as shown in the sample calculations in Appendix C, and the two values added gives 0.0221 horsepower. This is the value used for the power require to turn the rotor system. Anchoring the referred data to this point yields useable hover performance data for the RPH. Using this approach gives an estimate of the lifting capabilities of the RPH under different altitude sea level conditions.

The 2 inch skid height is a 16.3 inches rotor height which is an in-ground-effect (IGE) hover height. The 35 inch skid height is 49.3 inches rotor height and is approximately 95% of the rotor diameter. This rotor height can be considered sufficiently high enough to be an out-of-ground-effect (OGE) hover.

Using the handbook maximum engine rpm equates to over 2.5 horsepower. This exceeds the horsepower that can be anticipated from this engine using the local hobbyists limits of 13000 engine rpm. Using this limit as the maximum results in 1.51 horsepower. Entering Figure B.13 or B.14 with this horsepower referred to sea level standard day, results in a maximum gross weight of 19.58 lbf at a skid height of 2 inches. Entering the same figures with the same referred horsepower results in a standard day maximum gross weight of 18.09 lbf at 35 inches skid height. This gives a useful load of approximately 80-90% of basic weight. This amount of useful load is a bit high, but considering the data, is reasonable.

One of the methods of presenting data outline in [Ref. 5] allow the estimation of the hover ceiling for a given helicopter. This method requires manufaturer data on the ESHP available at different pressure altitudes. this data is not available; therefore, the hover ceiling for this RPH cannot be established.

The least amount of variation in the load cell voltage was observed at the 35 inch hover height. This may be due to the down wash of the rotor not having as much impact on the flooring; therefore, transmitting less vibration back to the load cell.

The tip-path-plane oscillations could be due to the thrust vector not being in-line with the sliding shaft.

Because the mounting plate is visually aligned with the rotor shaft, the thrust going through the center-of-gravity could not be in line with the sliding shaft. This misalignment could cause a bending moment on the sliding shaft. The oscillations could be this interaction between the bending moment imposed and the sliding shaft elasticity.

The adjustment of the carburetor was very hazardous and probably should not have been attempted even though the manual [Ref. 2] suggested the procedure. An alternate method or a safer procedure is needed to adjust the carburetor.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. SUITABILITY OF THE EQUIPMENT

1. The RPH

Limited data was taken prior to the RPH becoming inoperable. The amount of time spent on learning the operation and maintenance of the RPH was far greater than expected. The many moving parts and required maintenance make the RPH a very complex teaching aid. This complexity limits the utility of the RPH in the academic environment. The reliable operation of the RPH was one of the limiting factors in taking data.

From the data taken, this RPH or ones similar have a large enough useful load to carry an instrumentation package of limited scope. This instrumentation package could be setup to take in-flight data.

2. The Thrust Stand

The thrust stand and associated equipment operated as designed and the data taken, when reduced, produced most of the expected results of hover performance. Reducing the vibrations experienced by the load cell would increase the confidence of the data.

3. Safety

The operation of the RPH in close vicinity of personnel and equipment and the method by which the motor is

tuned is not safe in the present form. The potential for a serious injury exists. Location should be changed or safety barriers installed around the RPH to prevent hazarding personnel or equipment.

B. RECOMMENDATIONS

1. General

The vibrations of the flooring transmitted to the load cell could be eliminated by isolating the floor from the sliding shaft. This could be done by (1) removing the low friction bearing mounted to the floor (2) disconnect the support stanchion from the bottom of the floor (3) mount the bearing on top of the support stanchion and (4) brace the support stanchion to the base support. These changes would isolate the load cell and sliding shaft from the flooring and still maintain the necessary rigidity.

For safety, a barrier of plexiglas or equivalent should be placed between the RPH and any personnel. This could be portable and not permanent but would eliminate the potential of an accidental injury. The operator would still be required to work in close proximity of the RPH during the starting procedure, but could move behind the plexiglas barrier to operate the controls.

For maintenance in adjusting the carburetor, a separate test stand should be bought or built. Several examples are given in the helicopter manual [Ref. 2]. By

mounting the RPH on a higher rigid platform would allow the operator to adjust the carburetor with sufficient clearance without danger of contacting the rotating rotor. The reason the sliding shaft could not do this job is because the RPH should not be started while resting solely on the load cell without damage to the load cell. If the sliding shaft were used, the RPH would be started with the sliding shaft all the way down, then raused to adjust the carburetor. If the carburetor were misadjusted, the sliding shaft would have to be lowered and the RPH restarted again. This would be extreamely time consuming. The load cell has a maximum force that can be applied prior to damage and this force can be exceeded during the starting procedure.

In flight performance can be gathered because the RPH has an adequate useful load. The sophistication (cost) necessary in the airborne package would probably prohibit the use of the RPH for inflight performance testing. The limited use in an academic environment would not justify the expense.

If the RPH is only to be used for hover performance, the gas engine could be replaced with an electric motor. This would eliminate the the exhaust fumes and the requirement to adjust the carburetor while the RPH is operating. In addition, the controls would not need to be battery powered but could be run by a transformer located with the test instrumentaion.

Test techniques utilized in full sized helicopter testing can be used in testing of remotely piloted helicopters. There may be some disparity in the actual data because in the RPH tested there is no independent control of the engine rpm and the rotor pitch. This could be corrected by adding another servo controlling only the engine rpm allowing independent control of the engine and rotor. This would compare directly with full sized helicopters. A standard rpm could be set and maintained with different pitch (thrust) being set.

2. Specific

The RPH should be used as an academic tool to demonstrate test techniques and show the relationships between rotor diameter, power required, and rotor height in hover performance. This recommendation is predicated on replacing the gas engine with an electric motor. This would eliminate much of the maintenance and additional equipment required to operate the RPH. Batteries would not be required and glofuel would not have to be stored. The safety barrier would not have to be elaborate because operation of the RPH could be done at a distance with only the instrumentation close enough to be seen clearly enough to take data. Additionally, this would allow the rpm to be controlled independently of the rotor pitch.

APPENDIX A
TABLES

TABLE I
LOAD CELL CALIBRATION DATA

Load Cell Output (m V.D.C.)	Weight on Load Cell (lbf)
0.187	0.0
1.317	1.0
2.438	2.0
3.587	3.0
4.707	4.0
5.071	4.315
5.857	5.0
6.194	5.315
7.315	6.315
8.460	7.315
9.578	8.315
10.724	9.315
11.848	10.315
12.970	11.315
14.104	12.315
15.220	13.315
16.362	14.315
17.480	15.315
18.597	16.315
19.663	17.315

NOTE: Excitation voltage of 9.004 volts D.C. on load cell
This data taken from Reference [Ref. 1]

TABLE II
MONSANTO DIGITAL COUNTER
CONVERSION

Counter (HZ)	Engine Frequency (HZ)	Engine RPM	ESHP (HP)	Rotor RPM
1667	166.7	10000	1.27	1250
1833	183.3	11000	1.35	1375
2000	200.0	12000	1.43	1500
2167	216.7	13000	1.51	1625
2333	233.3	14000	1.59	1750
2500	250.0	15000	1.68	1875
2667	266.7	16000	1.77	2000
2833	283.3	17000	1.87	2125
3000	300.0	18000	1.96	2250
3170	317.0	19000	2.42	2375

Data taken from Reference [Ref. 4]

TABLE III
ENGINE RPM TO ENGINE HORSEPOWER
CONVERSION

RPM (10^3)	Watts (10^3)	N-M/sec	Ft-lb/sec	In-lb/sec	ESHP (HP)
18.5	1.490	1490	1099.0	13188.2	2.00
18.0	1.460	1460	1076.9	12922.7	1.96
17.5	1.425	1425	1051.1	12612.9	1.91
17.0	1.392	1392	1026.7	12320.8	1.87
16.5	1.360	1360	1003.2	12037.6	1.82
16.0	1.317	1317	971.4	11657.0	1.77
15.5	1.287	1287	949.3	11391.5	1.72
15.0	1.255	1255	925.7	11108.2	1.68
14.5	1.225	1225	903.6	10842.7	1.64
14.0	1.187	1187	875.5	10506.3	1.59
13.5	1.157	1157	853.4	10240.8	1.55
13.0	1.125	1125	829.8	9957.6	1.51
12.5	1.095	1095	807.7	9692.0	1.46
12.0	1.063	1063	784.1	9404.8	1.43
11.5	1.040	1040	767.1	9205.2	1.39
11.0	1.013	1013	747.2	8966.2	1.35
10.5	0.987	987	728.0	8736.1	1.32
10.0	0.95	950	700.7	8408.6	1.27

Data taken from Reference [Ref. 4]

TABLE IV
RAW DATA

Run No.	Skid Height (in)	Weight Start (mv)	Counter No.	Load Cell (mv)
1	2	17.9	1740	16.0
2	2	17.9	1810	15.2
3	2	17.9	1930	13.5
4	10	17.7	1600	17.3
5	10	17.7	1720	16.4
6	10	17.7	1785	15.6
7	10	17.7	1885	14.6
8	35	17.6	1590	17.1
9	35	17.6	1760	15.9
10	35	17.6	1850	15.5
11	35	17.6	1790	16.2
12	35	17.6	1650	17.2

OAT: 19°C
Date: 10-28-86
In Hg: 30.11

Weight of Shaft: 4.78 lbf

Voltage Supply: SRC Division/Moxon Inc.
Model #3564
SerNo #14061

Voltage Meter: Fluke Digital Voltmeter
Model #8600A
SerNo #0855115

Digital Counter: Monsanto Counter Timer
Model 101A
SerNo #675A460

TABLE V
REDUCED DATA

Run Number	Skid Height (in)	Start Weight (lbf)	Load Cell (mv)	ESHP (HP)	Weight Test (lbf)	Excess Thrust (lbf)
1	2	15.69	14.00	1.31	17.38	1.69
2	2	15.69	13.30	1.35	18.09	2.39
3	2	15.69	11.78	1.40	19.60	3.91
4	10	15.51	15.15	1.25	15.87	0.36
5	10	15.51	14.35	1.30	16.68	1.16
6	10	15.51	13.65	1.34	17.38	1.86
7	10	15.51	12.76	1.38	18.26	2.75
8	35	15.42	14.98	1.24	15.87	0.45
9	35	15.42	13.91	1.32	16.93	1.51
10	35	15.42	13.56	1.37	17.29	1.86
11	35	15.42	14.17	1.34	16.67	1.25
12	35	15.42	15.06	1.27	15.78	0.36

Run Number	Counter Number	Engine RPM	Rotor RPM	ESHP Ref	Weight Ref	Weight Ref$^{3/2}$
1	1740	10440	1305	1.47	18.74	81.14
2	1810	10860	1358	1.34	18.02	76.49
3	1930	11580	1448	1.15	17.18	71.18
4	1600	9600	1200	1.79	20.24	91.03
5	1720	10320	1290	1.51	18.40	78.92
6	1785	10710	1339	1.38	17.80	75.11
7	1885	11310	1414	1.21	16.78	68.73
8	1590	9540	1193	1.82	20.49	92.76
9	1760	10560	1320	1.43	17.85	75.39
10	1850	11100	1388	1.27	16.49	66.94
11	1790	10740	1343	1.37	16.98	70.00
12	1650	9900	1238	1.66	18.92	82.30

Date: 28 Oct 86
OAT: 19°C
Baramoter: 30.11 in Hg

APPENDIX B
FIGURES, PHOTOS, AND GRAPHS

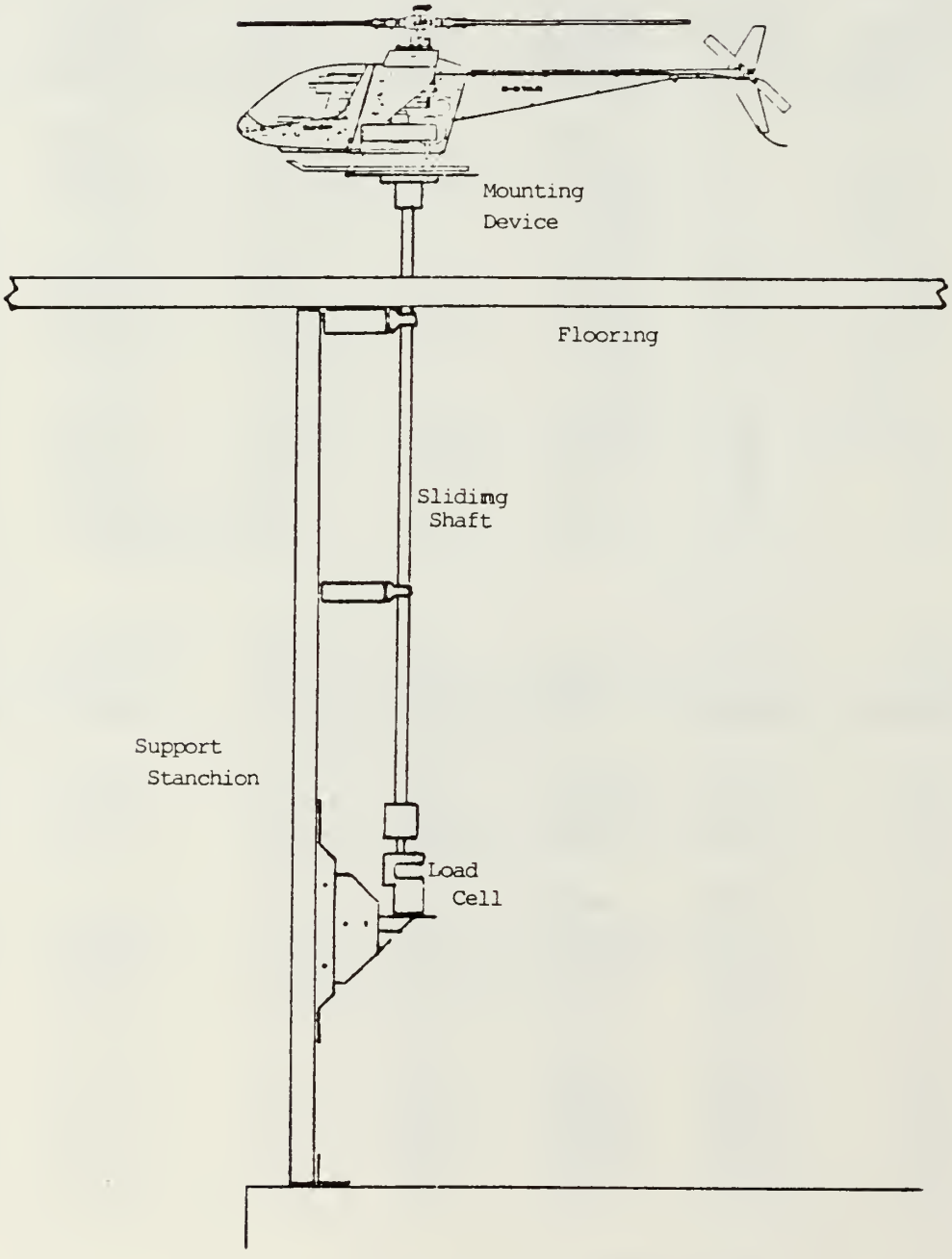

Figure 1
Sliding Shaft Configuration

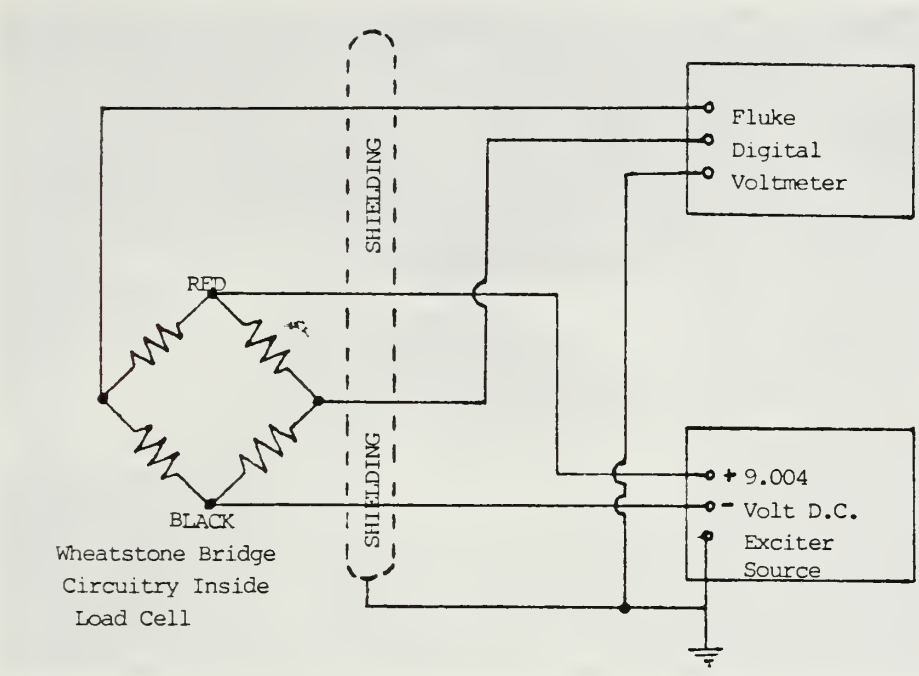

Figure 2
Load Cell Wiring Schematic

Figure 3
Magnetic Pick Up for RPM

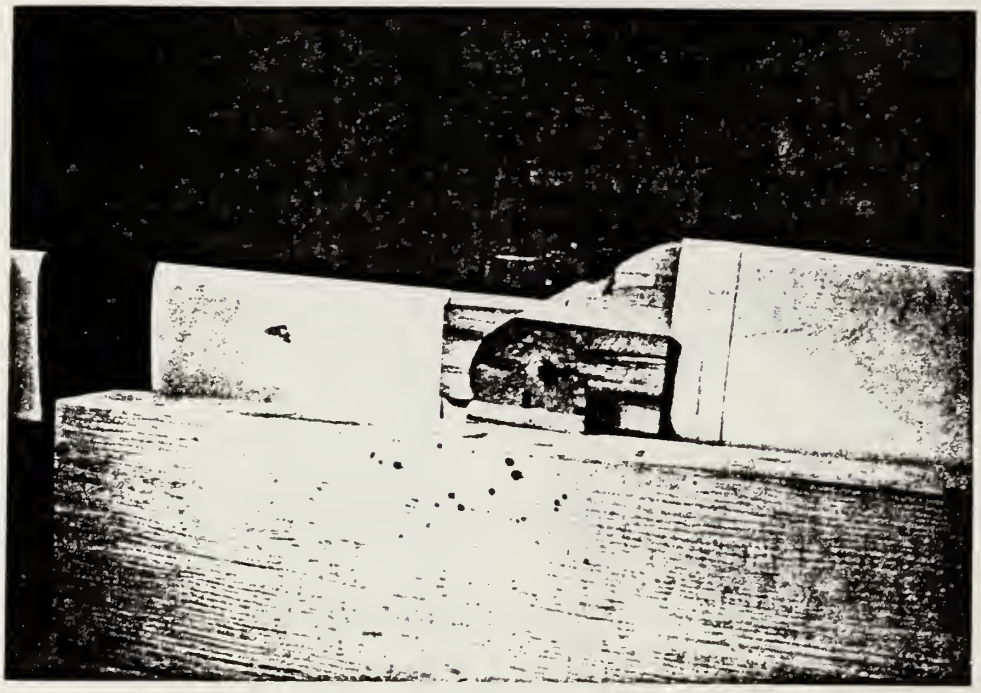

Figure 4
Blade Balancing Method

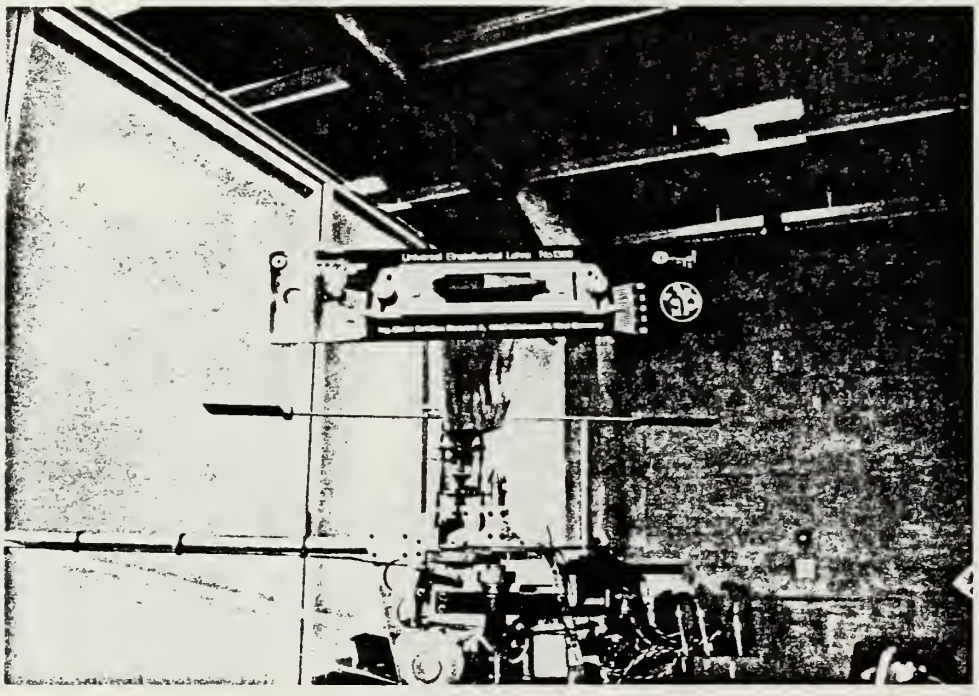

Figure 5
Blade Pitch Setting Device

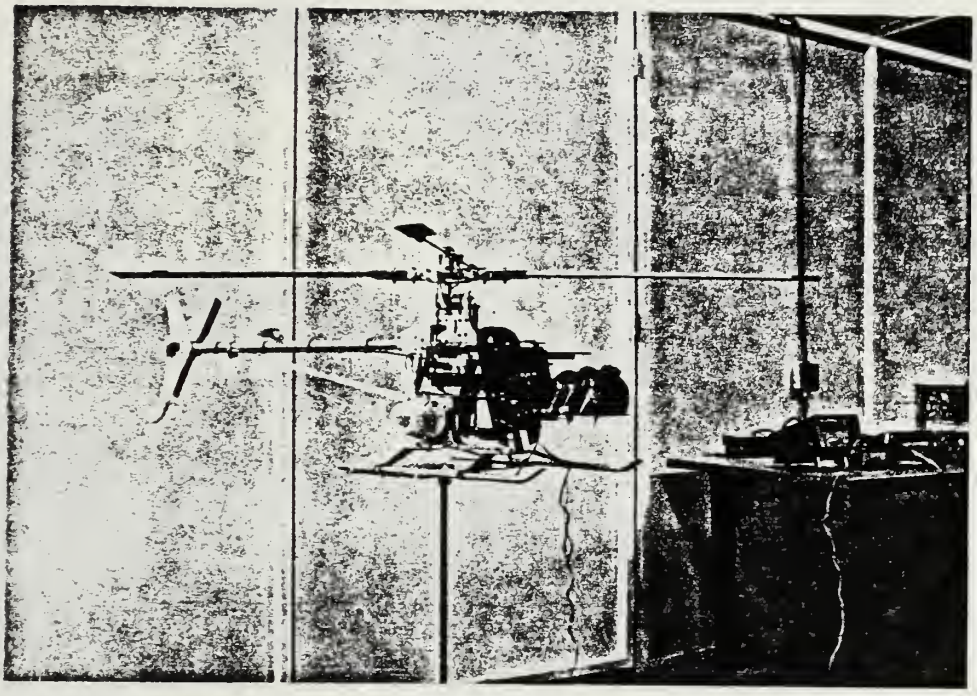

Figure 6
Heli-Star Helicopter without Nose Cover

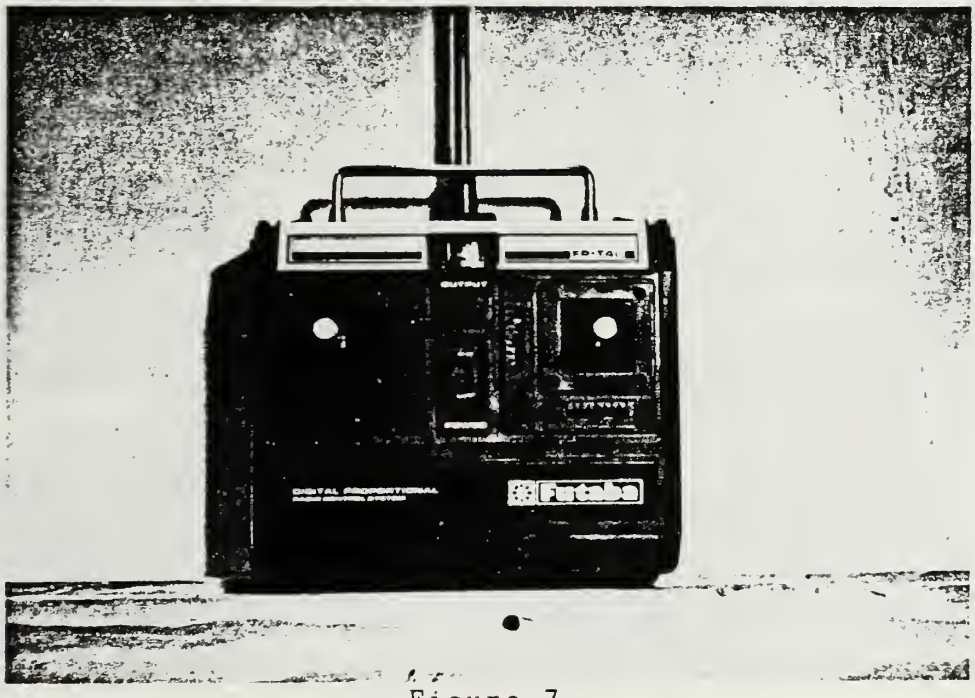

Figure 7
Model FP-4L Futaba Radio Controller

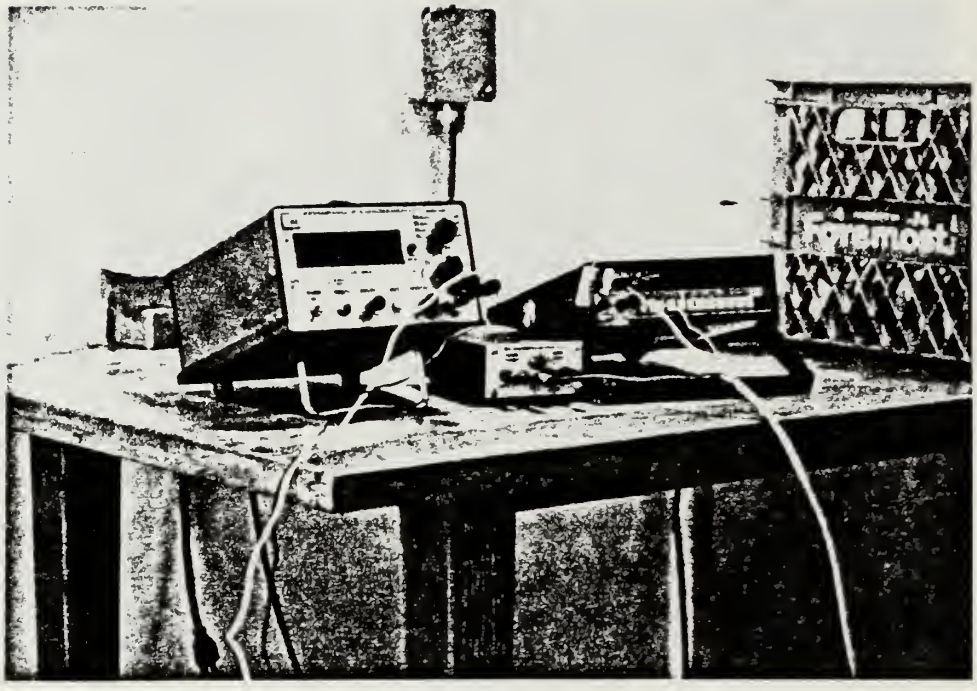

Figure 8
Test Equipment

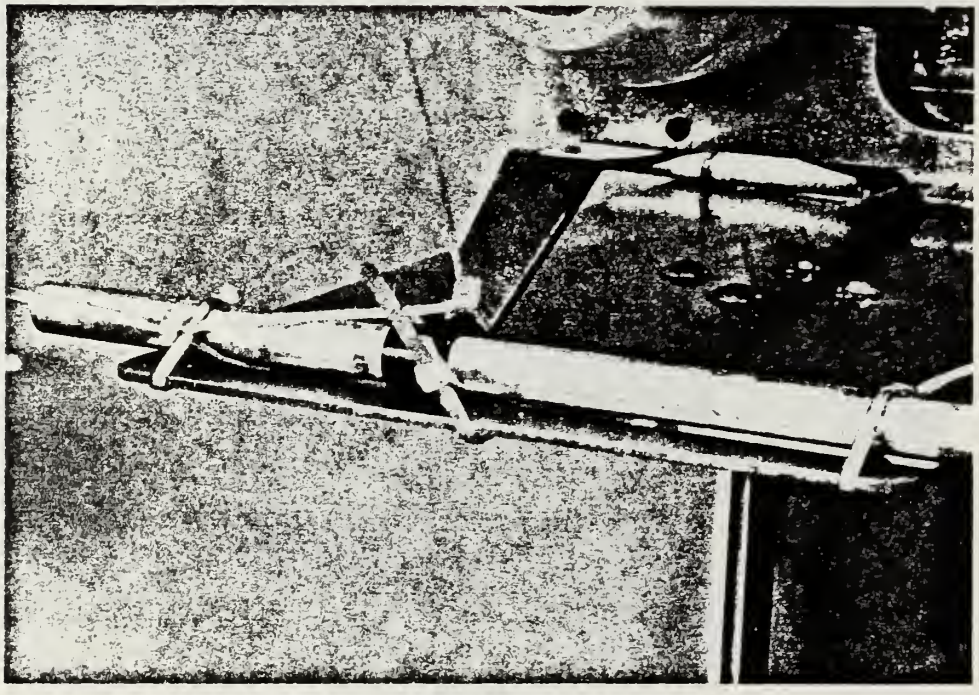

Figure 9
Heli-Star Mounting Plate Devices

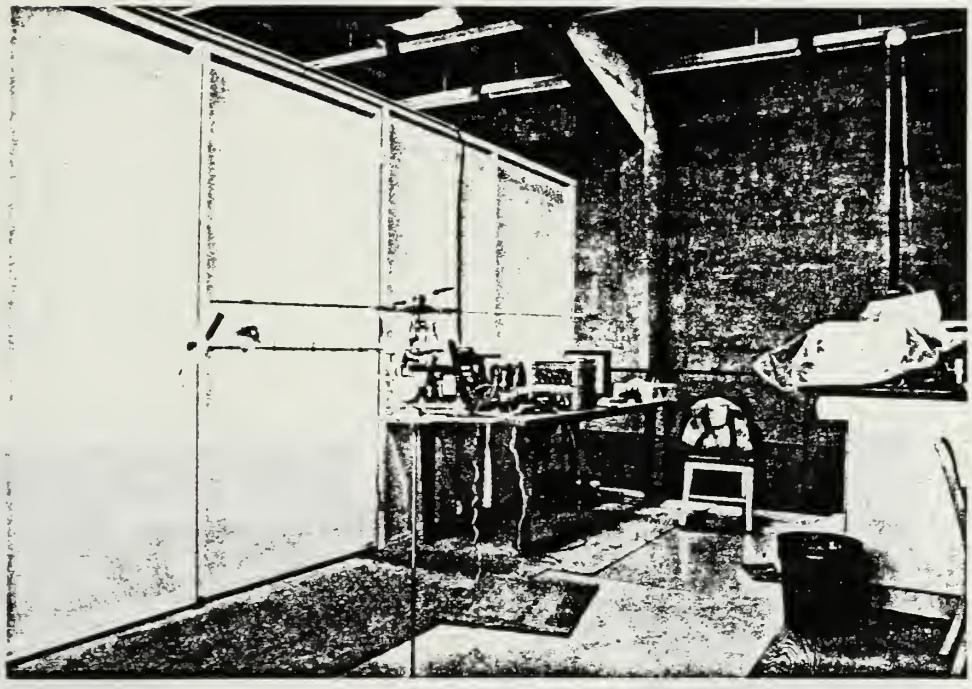

Figure 10
Test Area View 1

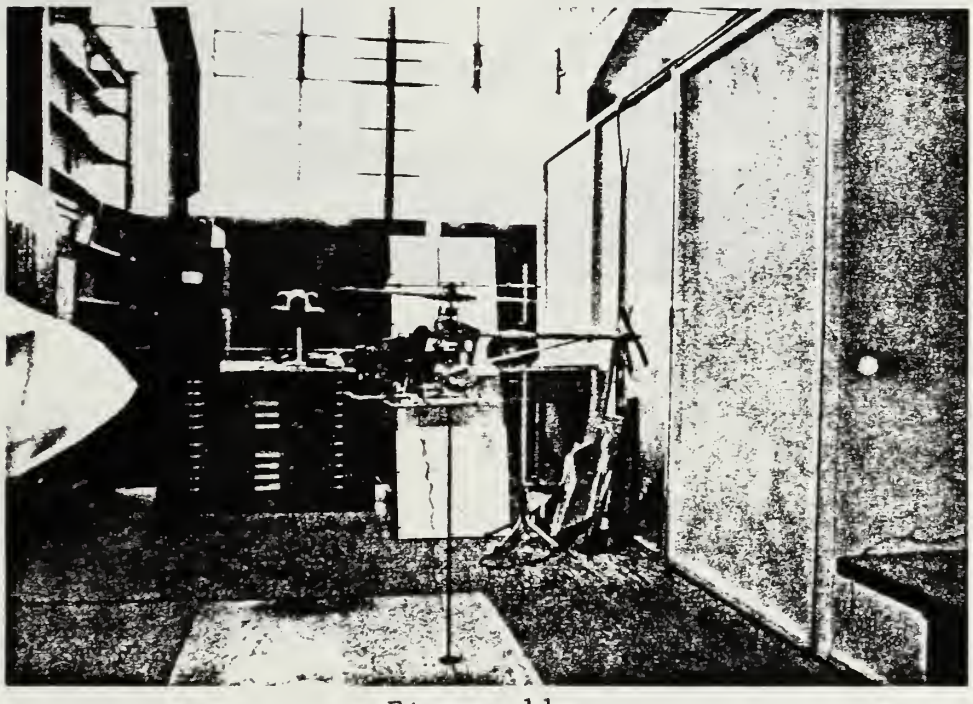

Figure 11
Test Area View 2

Figure 12
Test Area View 3

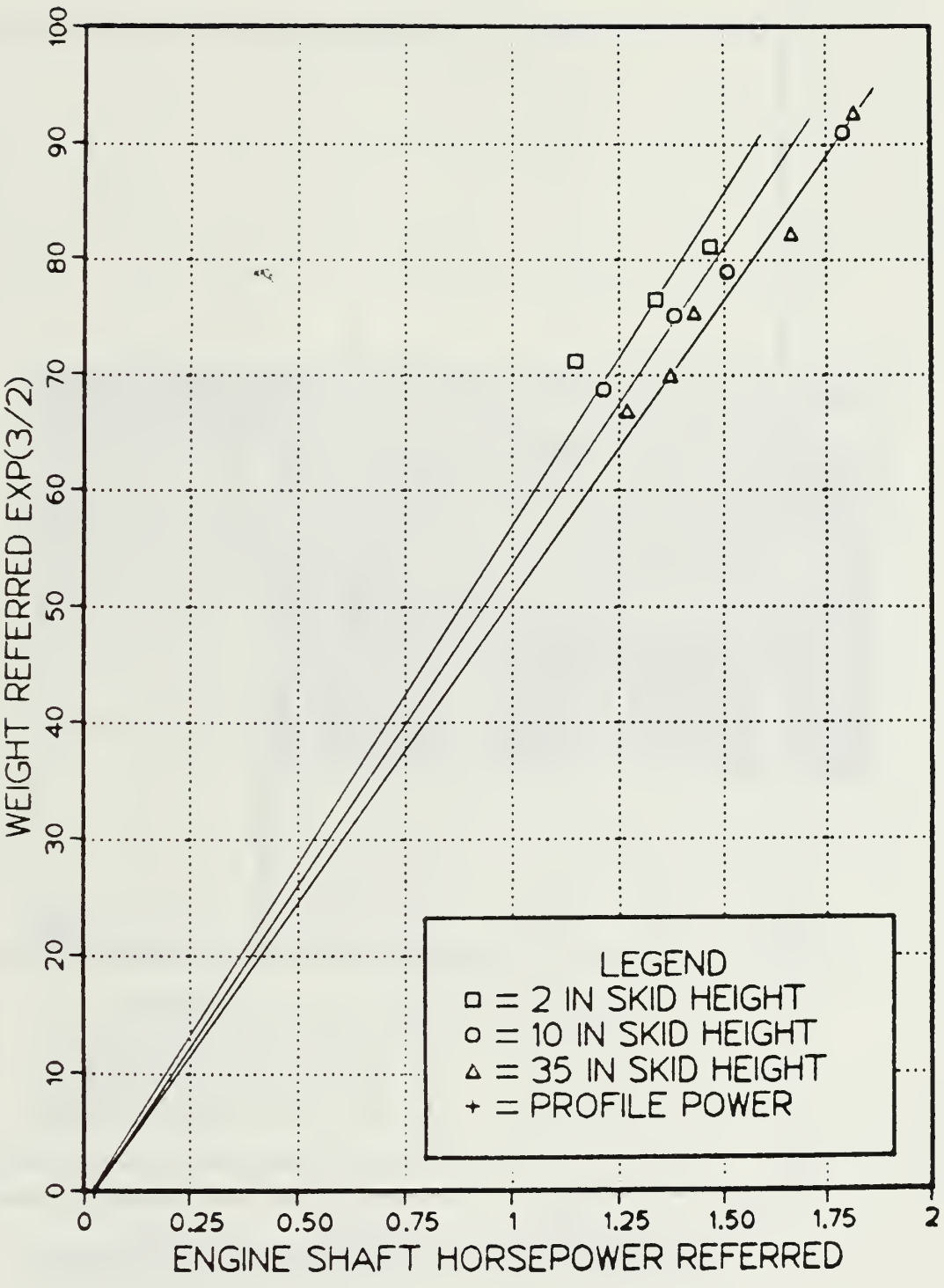

Figure 13
Weight Referred$^{3/2}$ vs. ESHP Referred

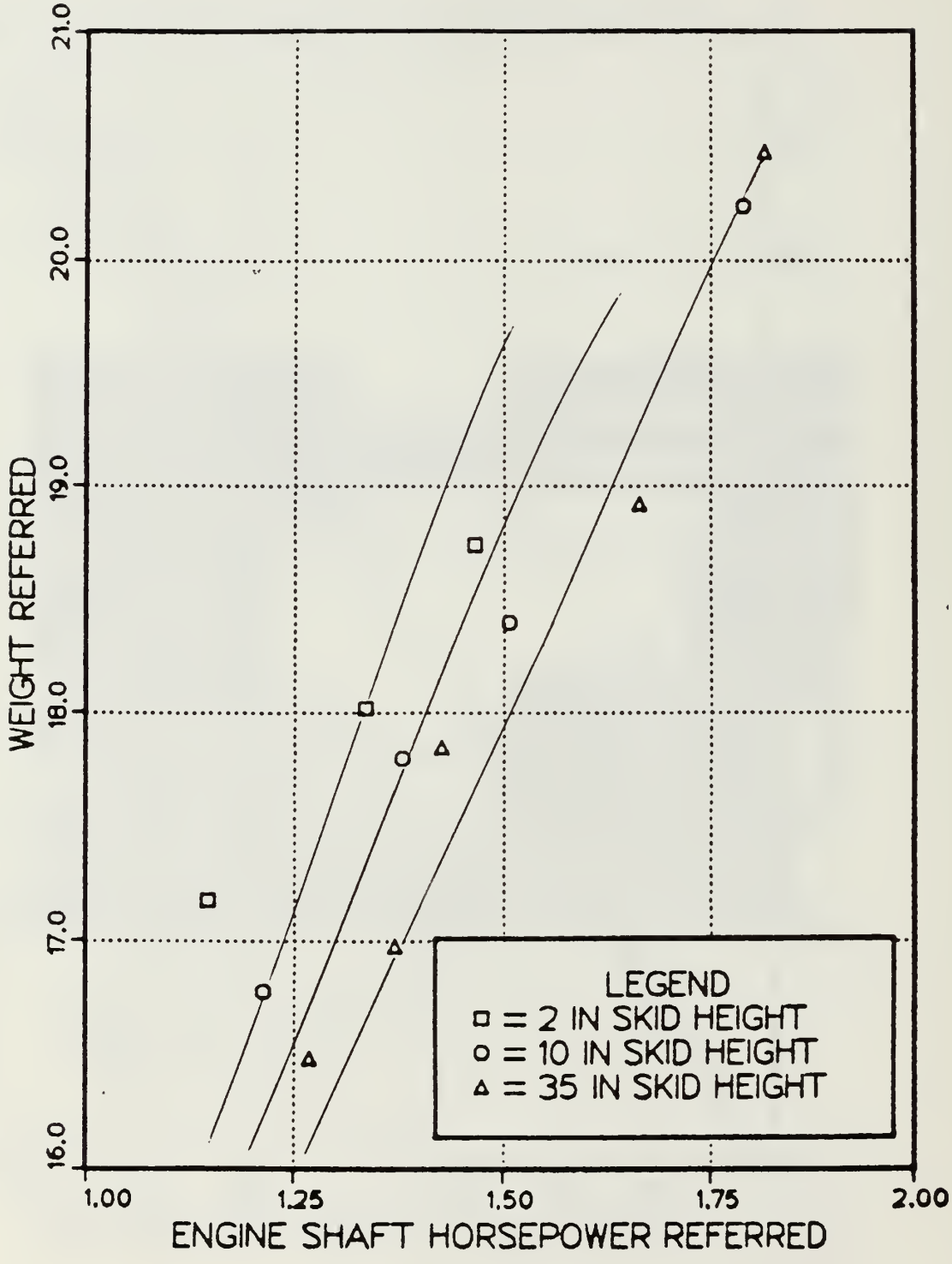

Figure 14
Weight Referred vs. ESHP Referred

Figure 15
Test Area Flooring

APPENDIX C
SAMPLE CALCULATIONS

Profile Power of the Main Rotor

R = radius = 26.16 inches = 2.18 feet

$NR_{standard}$ = 1350 rpm - - standard rotor rpm

$\Omega = 1350 \cdot 2\pi \cdot 1/60 = 141.4$ rad/sec

Rotor Solidity:
$\sigma_r = (b \cdot c)/(\pi \cdot R) = (2 \cdot c)/(\pi \cdot R) =$
6.255×10^{-2}

assume a C_{do} of 0.01 (high-conservative value)

Air Density at Sea Level
$\rho = 2.37691 \times 10^{-3}$ lb-sec^2/ft^4

A = area disc = πR^2 = 2148.29 in^2 = 14.92 ft^2

$(\Omega \cdot R)^2 = 2.927 \times 10^7$ ft^3/sec^3

$P_{oMR} = 1/8 \cdot \sigma_r \cdot C_{do} \cdot \rho \cdot A \cdot (\Omega R)^3$

P_{oMR} = 81.21 ft-lb/sec = 0.1477 HP

Profile Power of the Tail Rotor

Using the same formula for profile power as above with

R_{tr} = radius = 10.5 inches = 0.4375 ft

Tail rotor RPM = main rotor rpm * 3.617
= $1350 \cdot 3.617 = 4.88 \times 10^3$ rpm

$\sigma\sigma_{tr}$ = 0.1213

again assume C_{do} = 0.01

then P_{otr} = 2.426 ft-lbf/sec = 0.00411 HP

Using $P_{o\ total} = P_{oMR} + P_{otr} = 0.1477 + 0.00411$
= 0.0221 HP

APPENDIX D
BASIC PROGRAM LISITNG

```
'************************************************************
'*** Program to reduce data from data on RPH at the Naval
'*** Postgraduate School in conjunction with thesis by R. P.
'*** Cotten, Major, USMC
'************************************************************
'DATEE$ ..................................... DATE OF DATA
'OAT ........................................ AIR TEMPERATURE
'MERCURY.IN ................................. BAROMETRIC MEASUREMENT
'                                             IN MERCURY INCHES
'ROTOR.RPM.STD ..............,.............. STANDARD REFERENCE RPM
'THETA ...................................... T/TSSL
'DELTA ...................................... P/PSSL
'SIGMA ...................................... DELTA/THETA
'RUN.NO ..................................... DATA RUN NUMBER
'HOVER.HT ................................... HOVER HEIGHT OF THE
'                                             SKIDS ABOVE THE DECK
'WT.START ................................... STARTING WEI
'                                             RPH AT EACH NEW
'                                             HOVER HEIGHT
'COUNTER.NO ................................. MONSANTO DIGITAL COUNT
'                                             NUMBER FOR RPM
'LOAD.CELL ................................... READING OF THE LOAD
'                                             CELL
'A() ......................................... RUN NUMBER (RUN.NO)
'B() ......................................... HOVER HEIGHT (HOVER.HT)
'C() ......................................... WEIGHT AT START OF DATA
'                                             AT EACH HOVER HEIGHT
'                                             (WT.START)
'D() ......................................... COUNTER NUMBER
'                                             (COUNTER.NO)
'E() ......................................... LOAD CELL READING
                                              (LOAD.CELL)
'F() ......................................... ENGINE RPM
'G() ......................................... ENGINE SHAFT HORSEPOWER
'H() ......................................... ROTOR RPM
'I() ......................................... EXCESS THRUST
'J() ......................................... TEST WEIGHT - WEIGHT
'                                             THE ROTOR SEES
'K() ......................................... REFERRED ESHP
'L() ......................................... REFERRED WEIGHT ^3/2
'M() ......................................... COEFFICIENT OF THRUST
'N() ......................................... COEFFICIENT OF
'                                             THRUS^3/2
'O() ......................................... POWER COEFFICIENT
'P() ......................................... FIGURE OF MERIT
```

```
'PFORMAT $ ..................... PRINTING FORMAT
'****************** DIMENSION STATEMENTS ******************
DIM A(50):DIM B(50):DIM C(50):DIM D(50):DIM E(50):DIM F(50)
DIM G(50):DIM H(50):DIM I(50):DIM J(50):DIM K(50):DIM L(50)
DIM M(50):DIM N(50):DIM O(50):DIM P(50)
'******************** CONSTANTS ****************************
PI = 3.141593
ROTOR.RADIUS = 26.15/12    'RADIUS OF MAIN ROTOR IN
RHO.SSL = 2.37691E-3    'DENSITY OF AIR AT SEA LEVEL
 SLUGS/FT^3
OMEGA.CONVERSION = 1.047197E-1  'CONVERSION FROM RPM TO
 RADIANS/SEC
AREA.DISC = PI*ROTOR.RADIUS^2
'***************** BEGIN PROGRAM ****************************
  PFORMAT1$ = "          ##         ##     ##.###   ##.##
 #.###   ##.###   #.###"  'PRINT FORMAT
  PFORMAT2$ = "          ##           ####      #####
 ####      #.###     ##.###"     'PRINT FORMAT
  PFORMAT3$ = "          ##     ####^^^^    ####^^^^
 ####^^^^      ####^^^^"   'PRINT FORMAT
K001A:
    CLS:LOCATE 10,15
    INPUT"Do you want to input new data?  (Y/N)";ANS$
    IF ((ANS$="y") OR (ANS$="Y")) THEN
        CLS
        GOTO K001
      ELSEIF ((ANS$="n") OR (ANS$="N")) THEN
        CLS
        GOTO K001B
      ELSE
        BEEP
        GOTO K001A
    END IF
K001B: '*************** inputs file data ***************
    LOCATE 10,15
    PRINT"Remember the file name should be YYMMDD
    LOCATE 11,15
    PRINT"   where Y=year, M=month, and D=day
    LOCATE 13,15
    INPUT"Input the file name of the stored data
       :",FILENAME$
      OPEN FILENAME$ FOR INPUT AS #1
      INPUT #1, DATEE$, OAT, MERCURY.IN,
       ROTOR.RPM.STD
      I=0
        WHILE NOT EOF(1)
          I=I+1
          INPUT #1, A(I), B(I), C(I), D(I),
           E(I)
        WEND
       CLOSE #1
```

```
    RUN.NO=A(I)
    SIGMA = (MERCURY.IN/29.92)/((OAT+273)/288)
  GOTO K007
K001: '********* input of data from console ******
  CLS
  LOCATE 10,5
    PRINT"INPUT THE FOLLOWING STARTING DATA
    PRINT
    INPUT"DATE DATA TAKEN  (YYMMDD)      ",DATEE$
    INPUT"AIR TEMPERATURE  (DEG C)       ",OAT
    INPUT"BAROMETRIC PRESSURE (IN Hg)    ",MERCURY.IN
    INPUT"STANDARD MAIN ROTOR RPM
         ",ROTOR.RPM.STD
K002:
   LOCATE 24,15
    INPUT"DO YOU WANT TO MAKE ANY CHANGES? (Y/N)";ANS$
    IF ((ANS$="y") OR (ANS$="Y")) THEN
        CLS
        LOCATE 10,1
        GOTO K001
      ELSEIF ((ANS$="n") OR (ANS$="N")) THEN
        CLS
        GOTO K003A
      ELSE
        BEEP
        GOTO K002
    END IF
K003A:
    'THETA = (OAT+273)/288
    'DELTA = MERCURY.IN/29.92
    SIGMA = (MERCURY.IN/29.92)/((OAT+273)/288)
K003:
    LOCATE 5,3
      PRINT"INPUT 99 WHEN YOU NO LONGER WISH TO
              INPUT DATA !!!!"
    LOCATE 10,5
      PRINT"       LAST RUN NUMBER     ";RUN.NO
    LOCATE 12,5
      INPUT"RUN NUMBER
         ",QUICK.CHECK
        IF (QUICK.CHECK = 99) THEN
        GOTO K006
       ELSE
        RUN.NO = QUICK.CHECK
       END IF
    LOCATE 13,5
      INPUT"HOVER HEIGHT                 ",HOVER.HT
    LOCATE 14,5
      INPUT"BEGINNING WEIGHT             ",WT.START
    LOCATE 15,5
      INPUT"MONSANTO COUNTER NUMBER      ",COUNTER.NO
```

```
    LOCATE 16,5
      INPUT"LOAD CELL READING          ",LOAD.CELL

K004:
   LOCATE 24,15
    INPUT"DO YOU WANT TO MAKE ANY CHANGES? (Y/N)";ANS$
    IF ((ANS$="y") OR (ANS$="Y")) THEN
        CLS
        RUN.NO = RUN.NO-1
        GOTO K003
      ELSEIF ((ANS$="n") OR (ANS$="N")) THEN
        GOTO K005
      ELSE
        BEEP
        GOTO K004
    END IF
K005:
  A(RUN.NO)=RUN.NO
  B(RUN.NO)=HOVER.HT
  C(RUN.NO)=WT.START
  D(RUN.NO)=COUNTER.NO
  E(RUN.NO)=LOAD.CELL
  CLS:GOTO K003
K006:
          CLS
          FILENAME$=DATEE$    'Name of file
           is the date data taken
          OPEN FILENAME$ FOR OUTPUT AS #2
            PRINT #2, DATEE$, OAT,
             MERCURY.IN, ROTOR.RPM.STD
              FOR I=1 TO RUN.NO
                PRINT #2, A(I),
               B(I), C(I), D(I), E(I)
              NEXT I
          CLOSE #2
K007:
DEF FNWEIGHT (A)
  IF (A<1.317)THEN
    FNWEIGHT = (A-0.187)/1.13
  ELSEIF (A<2.438) THEN
    FNWEIGHT = ((A-1.317)/1.121)+1
  ELSEIF (A<3.587) THEN
    FNWEIGHT = ((A-2.438)/1.149)+2
  ELSEIF (A<4.707) THEN
    FNWEIGHT =((A-3.587)/1.12)+3
  ELSEIF (A<5.857) THEN
    FNWEIGHT = ((A-4.707)/1.15)+4
  ELSEIF (A<6.194) THEN
    FNWEIGHT = (((A-5.857)/0.337)*0.315)+5
  ELSEIF (A<7.315) THEN
    FNWEIGHT = ((A-6.194)/1.121)+5.315
```

```
  ELSEIF (A<8.460) THEN
    FNWEIGHT = ((A-7.315)/1.145)+6.315
  ELSEIF (A<9.578) THEN
    FNWEIGHT = ((A-8.460)/1.118)+7.315
  ELSEIF (A<10.724) THEN
    FNWEIGHT = ((A-9.578)/1.146)+8.315
  ELSEIF (A<11.848) THEN
    FNWEIGHT = ((A-10.724)/1.124)+9.315
  ELSEIF (A<12.970) THEN
    FNWEIGHT = ((A-11.848)/1.120)+10.315
  ELSEIF (A<14.104) THEN
    FNWEIGHT = ((A-12.970)/1.134)+11.315
  ELSEIF (A<15.220) THEN
    FNWEIGHT = ((A-14.104)/1.116)+12.315
  ELSEIF (A<16.362) THEN
    FNWEIGHT = ((A-15.220)/1.142)+13.315
  ELSEIF (A<17.480) THEN
    FNWEIGHT = ((A-16.362)/1.118)+14.315
  ELSEIF (A<18.597) THEN
    FNWEIGHT = ((A-17.480)/1.117)+15.315
  ELSEIF (A<=19.663) THEN
    FNWEIGHT = ((A-18.597)/1.066)+16.315
  ELSE
    CLS:LOCATE 12,0
    PRINT"Load cell not calibrated beyond a reading of
          19.66 mv."
  END IF
END DEF
K009:
  FOR Z=1 TO RUN.NO
    C(Z) = FNWEIGHT(C(Z))       'STARTING WEIGHT IN LBS
    E(Z) = FNWEIGHT(E(Z))       'WEIGHT THE LOAD CELL
 SHOWS IN LBS
    F(Z) = D(Z)*6               'ENGINE RPM
      '****** ESHP ******
    G(Z) = (5.91E-5 * F(Z) +0.363)/746E-3
      '****** ROTOR RPM ***
    H(Z) = F(Z)/8
      '***** EXCESS THRUST **
    I(Z) = C(Z) - E(Z)          'THRUST EXCESS = WEIGHT
     - LOAD CELL WEIGHT
      '***** TEST WEIGHT *******
    J(Z) = I(Z) + C(Z)          'TEST WEIGHT = THRUST
      EXCESS + WEIGHT
      '***** ESHP REF *********
    K(Z) = (G(Z)/SIGMA)*((ROTOR.RPM.STD/H(Z))^3)
      '***** WEIGHT REF **********
    L(Z) = ((J(Z)/SIGMA)*((ROTOR.RPM.STD/H(Z))^2))^1.5
      '***** THRUST COEFFICIENT ******
    M(Z) =
(J(Z)/SIGMA)*(1/((OMEGA.CONVERSION*ROTOR.RADIUS*H(Z))^2))*(1
```

```
/AREA.DISC)*(1/RHO.SSL)
      '***** THRUST COEFFICIENT ^3/2 ******
    N(Z) = M(Z)^1.5
      '***** POWER COEFFICIENT *******

    O(Z) =
550*G(Z)/SIGMA*(1/AREA.DISC)*(1/((OMEGA.CONVERSION*ROTOR.RAD
IUS*H(Z))^3))*(1/RHO.SSL)
      '***** FIGURE OF MERIT *******
    P(Z) = 0.707*N(Z)/O(Z)
  NEXT Z
'********************* data to line printer ***********
K010:
  LPRINT:LPRINT
  LPRINT"          DATE: ";DATEE$"     OAT: ";OAT;"DEG C
BAROMETER: ";MERCURY.IN
  LPRINT
     '"          ##          ##     ##.###    ##.##
#.###    ##.###    #.###"   'PRINT FORMAT
  LPRINT"          RUN        SKID   START     LOAD
WEIGHT   EXCESS
  LPRINT"         NUMBER     HEIGHT  WEIGHT    CELL      ESHP
TEST    THRUST
  LPRINT"                     (in)    (lbf)    (mV)      (HP)
(lbf)    (lbf)
    FOR Q=1 TO RUN.NO
      LPRINT USING
PFORMAT1$;A(Q);B(Q);C(Q);E(Q);G(Q);J(Q);I(Q)
      IF (Q>24) THEN GOTO K011
    NEXT Q
K011:
  LPRINT
     '"          ##            ####       #####      ####
#.###     ##.###"      'PRINT FORMAT
  LPRINT"          RUN          COUNTER    ENGINE     ROTOR
ESHP      WEIGHT
  LPRINT"         NUMBER        NUMBER       RPM        RPM
REF       REF ^3/2
    FOR Q=1 TO RUN.NO
      LPRINT USING
PFORMAT2$;A(Q);D(Q);F(Q);H(Q);K(Q);L(Q)
      IF (Q>24) THEN GOTO K012
    NEXT Q
  LPRINT CHR$(12)
  LPRINT:LPRINT
  LPRINT"          DATE: ";DATEE$"     OAT: ";OAT;"DEG C
BAROMETER: ";MERCURY.IN
  LPRINT
     '"          ##     ####^^^^    ####^^^^
####^^^^      ####^^^^"   'PRINT FORMAT
  LPRINT"          RUN     THRUST      THRUST       POWER
```

```
FIGURE
  LPRINT"        NUMBER   COEFF        COEFF        COEFF
OF MERIT
  LPRINT"                                ^3/2
    FOR Q=1 TO RUN.NO
      LPRINT USING
PFORMAT3$;A(Q),M(Q),N(Q),O(Q),P(Q)
    NEXT Q
  LPRINT CHR$(12)
END '******************** 1ST END ********************
KO12:
  LPRINT CHR$(12)
  LPRINT:LPRINT
  LPRINT"          DATE: ";DATEE$"     OAT: ";OAT;"DEG C
BAROMETER: ";MERCURY.IN
  LPRINT
     '"          ##         ##     ##.###   ##.##
#.###   ##.###   #.###"  'PRINT FORMAT
  LPRINT"          RUN        SKID   START    LOAD
WEIGHT   EXCESS
  LPRINT"        NUMBER     HEIGHT  WEIGHT   CELL     ESHP
TEST    THRUST
  LPRINT"                     (in)    (lbf)   (mV)     (HP)
(lbf)    (lbf)
    FOR Q=26 TO RUN.NO
      LPRINT USING
PFORMAT1$;A(Q);B(Q);C(Q);E(Q);G(Q);J(Q);I(Q)
    NEXT Q
KO13:
  LPRINT
     '"          ##            ####      #####     ####
#.###     ##.###"     'PRINT FORMAT
  LPRINT"          RUN           COUNTER   ENGINE    ROTOR
ESHP      WEIGHT
  LPRINT"          NUMBER        NUMBER     RPM       RPM
REF       REF ^3/2
    FOR Q=26 TO RUN.NO
      LPRINT USING
PFORMAT2$;A(Q);D(Q);F(Q);H(Q);K(Q);L(Q)
    NEXT Q
  LPRINT CHR$(12)
  LPRINT:LPRINT
  LPRINT"          DATE: ";DATEE$"     OAT: ";OAT;"DEG C
BAROMETER: ";MERCURY.IN
  LPRINT
     '"          ##    ####^^^^    ####^^^^
####^^^^      ####^^^^"   'PRINT FORMAT
  LPRINT"          RUN    THRUST      THRUST       POWER
FIGURE
  LPRINT"        NUMBER  COEFF       COEFF        COEFF
OF MERIT
```

```
  LPRINT"                    ^3/2
    FOR Q=1 TO RUN.NO
      LPRINT USING
PFORMAT3$;A(Q),M(Q),N(Q),O(Q),P(Q)
    NEXT Q:LPRINT:LPRINT CHR$(12)
END '*************** END END END *****************
```

LIST OF REFERENCES

1. Urda, Theodore J., Lieutenant, U.S. Navy, Design of a Vertical Thrust Test Stand, M. S. Thesis, Naval Postgraduate School, Monterey, California, March 1986.

2. Schluter, Dieter, Radio Controlled Helicopter Manual Argus Books Ltd., 1983.

3. Hintze, Charles J., Major, U.S. Army, Construction and Use of a Radio Controlled Model Helicopter for Research, M. S. Thesis, Naval Postgraduate School, Monterey, California, March 1985.

4. Mills, D. M., "Preparations for Hover Performance Testing of a Remotely Piloted Helicopter," paper presented to Professor D. M. Layton, Naval Postgraduate School, 16 September 1985.

5. U. S. Naval Test Pilot School USNTPS-FTM-102, Helicopter Performance, 28 June 1968.

BIBLIOGRAPHY

Layton, Donald M., Helicopter Performance, Matrix Publishers, 1984

U. S. Naval Test Pilot School USNTPS-T-No. 1, Principles of Helicopter Performance, by R. B. Richards, 8 March 1968

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